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A COMPUTER CONTROLLED TELESCOPE

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The Space Astronomy Laboratory of the University of Wisconsin has recently installed a computer controlled telescope system at the University's Pine Bluff Observatory. Although not the first remote controlled system, it is the first such system which operates effectively with no human observer present during the entire observing evening.

Using a PDP-8 computer, surplus parts, and electronics designed by undergraduate students; the arrangement is noteworthy for its simplicity and economy as well as its originality.

Normal astronomical observing requires the presence of at least one highly trained observer. Stars must be sighted visually, and the equipment must be set up and operated by hand. Normal observing is night work, and is therefore performed at lowered human efficiency. If the evening clouds up, the observer must sit and wait. With this automatic system, the astronomer need only set up the equipment and provide a list of stars. Data will be collected automatically during the evening and the system will shut itself down in the morning or if the weather turns foul.

The addition of a computer into such a system also allows real-time data reduction. Normal observing is limited to data collection, with the reduction done later; whereas, a computer in the control system allows a certain amount of data to be analyzed immediately. Perhaps the nicest advantage of an automatic system is its weather independence. To eliminate air shimmering, the interior of a telescope dome must remain at the outside temperature. As the best observing in Wisconsin occurs in the winter when a zero degree night is normal, a computer at the controls instead of a man can eliminate a lot of foot stomping and shivering.

As this system is a prototype, the equipment used is somewhat non-standard. The telescope is an eight-inch reflector with a photomultiplier tube to measure light and a set of filters to limit observing to various wavelength bands. It incorporates two aperture sizes and can vary the exposure to adjust for different star brightnesses. This instrument is an offshoot of the NASA OAO satellite program and was specifically designed to be remotely operated. It is driven by two small stepper motors on the north-south and east-west axes, and its position is read by two encoders on the same axes.

The instrument is mounted in a small metal shed a few hundred feet from the main observatory and is connected to the PDP-8 in the observatory basement via a tunnel. The shed itself is fixed with a movable roof and sides which are also operated by the computer. The entire system is driven by the PDP-8 through a rack of control electronics also located in the basement, most of which was designed and built by students.

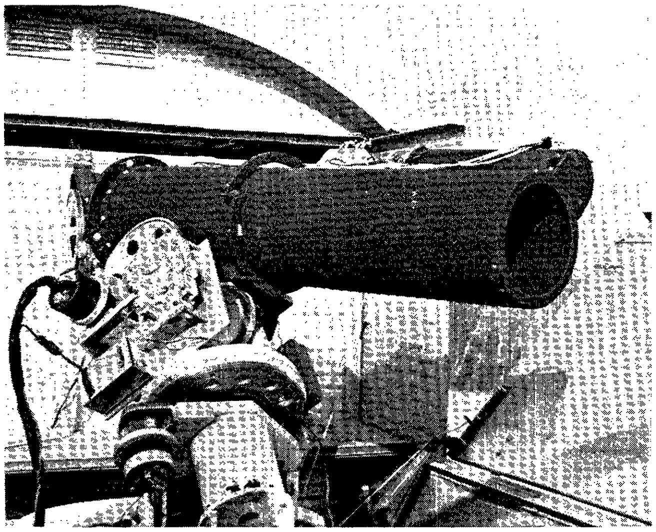

Fig. 1. The automatically controlled eight-inch telescope in normal rest position. The photomultiplier tube is in the housing on top of the instrument; the telescope control electronics is behind this. North-south drive train is clearly visible. The shed enclosing the telescope is in its open position with roof back and side flaps lowered.

The computer used is a basic 4K PDP-8. The only exotic features added are an A-D converter, power interrupt and auto restart, digital multiplexers, special purpose commands, and a loudspeaker on the link bit. Output is through a Kleinschmidt 40 cps teleprinter, input is standard ASR-33.

The PDP-8 has proven to be quite flexible for this purpose, performing a wide variety of functions. It maintains and searches a sequential star list of up to twelve stars, checking to see if the star is above the horizon, and slewing the telescope to the supposed star position if it is available. As the total gear slop of almost half a degree generally precludes finding the star in the aperture immediately, the computer can search a preset area of sky to find it. Once found, the star is centered in the aperture, and actual photometric observing takes place. Once this is done, a partial data reduction which includes expected errors for each data point is calculated and printed, and the system then proceeds to the next star in the list. Upon completion of each cycle through the list, a more detailed reduction is computed and printed.

During the observing sequence, the machine also checks for rain, wind, sudden barometric pressure changes, and sky brightness. If any of these factors exceed limits, the observing will stop, the telescope will be lowered, and the shed will be automatically closed. The computer will also shut off power to the instrument and will turn off the teleprinters. If desired, it can be set to restart observing again automatically at next nightfall, or if conditions become favorable again. The system does not shut down for cloudiness, but waits a half hour and then attempts to continue observing in hopes that the sky might clear up.

The power of the computer in a system such as this is perhaps best illustrated by the problems encountered in moving the telescope. Motion is accomplished by four instructions which move the appropriate motor one step in either direction, so that there is a command to step once east, west, etc. The speed of motion can then be varied by adjusting the intervals between issuing the motion instruction. In practice, however, the motors would not run in the range of about 100 to 200 cycles; so that although an optimum running speed was 500 cycles, the inertia of the system required that they be started at 250 cycles and gradually speeded up. It was also discovered that they would occasionally stall, and on starting would often go in the opposite direction from that commanded. This presented some programming problems.

One of the two position encoders also became troublesome, so that it was regularly giving an incorrect position reading whenever the instrument was moving south. This made it quite difficult for any general routine to figure out where the telescope was pointed at a given instant.

These problems, which at first seemed quite formidable, were solved by making full use of the machine's capabilities. A dynamic slewing method was adopted, in which each single motor step was followed by a complete position recomputation. This recomputation checks for stalled or reversed motors, probable encoder errors, and adjusts motor speed as well. In spite of the fact that most of these computations are double precision, there is relatively little slowdown in slew speed because of the extra work. This technique has proven so flexible that it is being extended to dynamic star searching. Rather than stop the telescope to see if there is a star present, the star will be caught as it appears in the aperture while the telescope is moving.

Because of the limited size of the telescope, the system has been used for only two purposes to date: to determine the amount of junk in the atmosphere, and in a search for variable stars. The first use requires repeated observations on a set of standard stars to calculate the amount of light lost through the atmosphere; this data is then used in reducing data from the larger manual instruments. The other use is more interesting and is particularly adaptable to automatic control. There are a number of stars which

fluctuate in brightness over a period of a few hours, but with a variation of only two or three percent. Since atmospheric variation alone can easily cause a five percent change in apparent brightness, these small but real variations are difficult to catch. To find them, it is necessary to repeatedly alternate observations on the variable and on a non-varying standard star over the course of an evening using the standard star to check on sky variations. This requires rapid moving from one star to the other all night long, a difficult job for a person but a simple task for a computer.

Future developments to the system might incorporate a data-phone link to larger machines for more detailed reduction, or a tie-in to a larger machine at the observatory which might control the main telescopes as well. The usefulness of a small computer in this application is certainly proven.

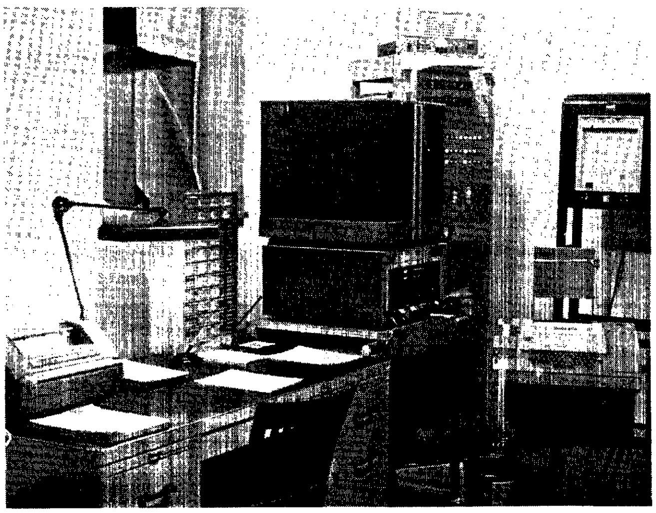

Fig. 2. The telescope control room, showing from left to right: Kleinschmidt Teleprinter on desk, PDP-8 computer, system electronics, ASR-33, and chart recorder.

This work was accomplished with the support of NASA Contracts NAS5-1348 and NSG-618.

DECUS PUBLICATIONS

Library Catalog - A new issue of the library catalog has recently been published. Copies have been sent to all DECUS members. Non-members may request copies from the DECUS Office, Maynard, Massachusetts.

Spring 1967 Proceedings - The proceedings of the "Display Symposium" held at Rutgers University in April are now available. Copies are being sent to all delegate members and meeting attendees. Others may request copies from the DECUS Office.

TABLE SORTS FOR THE PDP-8'S

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The Table Sort and Branch is a powerful and flexible programming tool. If a program must contend with a number of different characters (or up to 11-bit items) each of which can initiate different responses, the program must look up the addresses of the action that corresponds to a given symbol or bit pattern. If the symbols do not form a continuum, the programmer must find the most efficient method for determining the corresponding address.

The method that was used in the new editor and in the new octal debugging program is that of the Table Sort and Branch. This uses a simple subroutine to match up an input character with one member of a list of characters. The call to the subroutine is followed by: (1) the address of the list and (2) the difference between that list and a second list. The latter list contains the corresponding addresses. Thus, if a match is found in the first list, the difference (2) is added to the address of that match to compute the address in the second list which itself points to the action to be performed.

In addition to being simple and concise, although perhaps somewhat more time consumming than other methods, this technique has another advantage that is especially useful in a PDP-8: The tables may be placed at page boundaries to take up the slack that often occurs at the end of a page. This quickly results in an efficient use of all available core storage.

```
SORTB,  Ø               /Sort and Branch Routine.
        SZA
        DCA CHAR        /CHAR is assumed or set.
        TAD I SORTB
        ISZ SORTB
        DCA AXTEM
        TAD I AXTEM
        SPA
        JMP SEX
        CIA
        TAD CHAR
        SZA CLA
        JMP .-6
        TAD AXTEM       /Match found.
        TAD I SORTB
        DCA SORTB
        TAD I SORTB
        DCA SORTB
        JMP I SORTB
/////
SEX,    ISZ SORTB       /Match not found.
        CLA
        JMP I SORTB
```